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Tiller Persistence of Eight Intermediate Wheatgrass Entries Grazed at Three Morphological Stages

John R. Hendrickson,* John D. Berdahl, Mark A. Liebig, and James F. Karn

ABSTRACT

Intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey subsp. *intermedium*] provides high quality forage for hay and pasture in the Great Plains of North America but lacks persistence under grazing. We investigated the effect of grazing at early vegetative, mid-culm elongation, and boot stages on tiller persistence of three cultivars and five experimental lines of intermediate and pubescent wheatgrass [*T. intermedium* subsp. *barbulatum* (Schur) Barkw. & D.R. Dewey]. The study, located near Mandan, ND was seeded in 1997, hayed in 1998 and 1999, and grazed from 2000 to 2002. Four tillers were marked on one plant per plot in May 2000. Number of newly emerged tillers (tiller recruitment) and tiller mortality were recorded on the four original tillers and subsequently recruited tillers in mid-May, July, and September. Tiller replacement ratios, which incorporated cumulative recruitment and mortality, were greatest on plots grazed during early vegetative and mid-culm elongation. Tiller recruitment, tiller mortality, and tiller replacement ratio had a year × treatment interaction. In 2000, grazing during the early vegetative stage resulted in significantly higher tiller replacement ratios than grazing during late boot or no grazing, and grazing during mid-culm elongation and late boot had greater tiller recruitment but also greater tiller mortality than the other two treatments. Tiller replacement ratio had a grazing treatment × entry interaction in 2001. 'Mandan 1871' had the greatest tiller replacement ratio and tiller recruitment among entries. The results indicate time of grazing and cultivar selection influence the persistence of tillers of intermediate wheatgrass primarily through their effect on tiller recruitment.

Intermediate wheatgrass is a high-yielding perennial forage (Bittman et al., 2000; Suleiman et al., 1999) with excellent quality (Moore et al., 1995) that is utilized for pasture and hay in the Northern and Central Great Plains region of the USA. Many of the early Conservation Reserve Program (CRP) planting mixes in North and South Dakota (Allen et al., 2001) included intermediate wheatgrass. Malinowski et al. (2003) also evaluated intermediate wheatgrass as a cool-season component in grazing systems in the Southern Great Plains.

Despite its yield and quality, use of intermediate wheatgrass has been limited because of its poor persistence and competitive ability. Intermediate wheatgrass did not compete well with alfalfa (*Medicago sativa* L.) or with invasive plant species in Saskatchewan, Canada (Kilcher and Heinrichs, 1966; Holt and Jefferson, 1999). In other Saskatchewan studies, intermediate wheatgrass was reported to suffer severe winter injury 4 yr after stand establishment (Heinrichs and Clark, 1961). Campbell (1961) indicated that intermediate wheatgrass should not be recommended for dryland pastures intended to last longer than 3 yr. Heinrichs and Clark (1961) and Lawrence and Ashford (1966) both indicated that intermediate wheatgrass could not withstand intensive defoliation and recommended that it be used for hay rather than pasture. However, Bittman et al. (2000) suggested that 'Clarke' intermediate wheatgrass be considered for hay and pasture in northern Saskatchewan.

In perennial grasses, tillers are the basic units that determine future productivity (Murphy and Briske, 1992). Tiller production from recently formed axillary buds has also been shown to be the primary means of persistence in many perennial grasses (Hendrickson and Briske, 1997). Because perennial grass plants are essentially a collection of tillers, an understanding of tiller persistence should give managers an understanding of how their grazing strategy may affect stand persistence. Olson and Richards (1988) used a tiller replacement ratio, which incorporates new tiller emergence and tiller mortality to determine persistence of tiller populations.

The morphological stage of intermediate wheatgrass development should be considered in planning a grazing strategy (Mitchell et al., 1998). Defoliation between floral initiation and anthesis was most damaging to three warm-season grasses in the Missouri Ozarks (Vogel and Bjugstad, 1968). Grazing crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Shultes] after the culm elongation stage decreased the ability of crested wheatgrass to replace tillers (Olson and Richards, 1988).

Moore et al. (1995) evaluated four intermediate wheatgrass populations and determined that modest improvements in forage quality could have a positive impact on animal performance. However, while selection work has emphasized forage yield and quality, there is little information on how different tiller populations of intermediate wheatgrass persist under grazing.

We established a study near Mandan, ND to evaluate the impact of time of grazing on the persistence of eight cultivars and strains of intermediate wheatgrass. Our hypotheses were (i) morphological development stage at the time of grazing would affect the persistence of intermediate wheatgrass, and (ii) intermediate wheatgrass cultivars and experimental lines under grazing stress would differ in the ability of their tiller populations to persist.

MATERIALS AND METHODS

The study was conducted at the Northern Great Plains Research Laboratory at a field site located approximately 6 km south of Mandan, ND (46°46′ N, 100°50′ W). Soil at the study site was a Wilton silt loam (fine-silty, mixed, superactive frigid Pachic Haplustolls). Average annual precipitation from 1913

USDA-ARS, Northern Great Plains Res. Lab., Box 459, Mandan, ND 58554. Received 1 July 2004. *Corresponding author (hendricj@mandan.ars.usda.gov).

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Table 1. Entries grazed at three different morphological stages from 2000 to 2002 at Mandan, ND and their origin.

Entry	Origin
Caspian	Experimental population from USDA-ARS, Lincoln, NE.
Manska	Released in 1992 by USDA-ARS, Mandan, ND and Lincoln, NE in cooperation with USDA-SCS, Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln and the North Dakota Agricultural Experiment Station.
Oahe	Released in 1962 by South Dakota State Agricultural Experiment Station.
R-31	Direct increase of Russian Cultivar Rostovsky 31. Obtained from USDA-ARS, Lincoln, NE.
Reliant	Released in 1991 by USDA-ARS, Mandan, ND in cooperation with USDA-SCS and the North Dakota Agricultural Experiment Station
Mandan 1821	Experimental population USDA-ARS, Mandan, ND.
Mandan 1871	Experimental population USDA-ARS, Mandan, ND.
Mandan 1891	Experimental population USDA-ARS, Mandan, ND.

to 2003 at the study site was 410 mm, and long-term growing season precipitation (April to September) was 330 mm. Average maximum temperatures range from −6.7°C in January to 28.7°C in July.

The study area was fertilized with 30 kg ha^{-1} N in September 1996, seeded in May 1997 and hayed in mid-July 1998 and 1999. Before the study area was seeded, herbicide was applied and the area was tilled twice to control weeds. Seeding rate was approximately 100 seeds m^{-1} of row. Grazing treatments were implemented in 2000. There were three blocks, each of which contained three paddocks for a total of nine. Paddock size was 20 by 18 m, each containing 16 plots (2 by 9 m) arranged in two strips with eight plots per strip. Each of the eight entries (Table 1) was randomly assigned to one of the eight plots within each strip (Fig. 1). Border areas were seeded with a mixture of the eight entries.

In May 2000, one intermediate wheatgrass plant was randomly located within each plot in each paddock ($N = 144$), and four tillers on this plant were marked with colored telephone wires. These four tillers served as a baseline from which to monitor future tiller emergence and mortality. These tillers and all tillers that emerged later were monitored at regular intervals throughout the course of the study. The original four tillers of each plant were at the four- to six-leaf stage when first marked. The number of newly emerged tillers (tiller recruitment) and tiller mortality were determined on all originally marked tillers and any new tillers. The semirhizomatous nature of intermediate wheatgrass presented problems in determining if an observed new tiller had emerged from an existing marked tiller of the plant being measured. After examining a number of plants from the border areas, tillers emerging within 3 cm of an existing marked tiller and with their base orientated toward that tiller were classified as tillers derived from an existing marked tiller. Because the baseline tillers were marked in May 2000, tillers were monitored in mid-July and mid-September in 2000. At each different date, newly emerged tillers were marked with a different-colored wire. In 2001 and 2002, monitoring was done in mid-May, mid-July, and mid-September.

The experimental design was a split plot in randomized complete blocks with three replicates with unbalanced sample units. The main-plot factor was the grazing treatment, and entry was the subplot factor. In 2000, each paddock was assigned to one of the following grazing treatments: (i) grazed during the four- to six-leaf stage (early vegetative), (ii) grazed when the stems had approximately two palpable nodes (mid-culm elongation), and (iii) grazed during late boot (late boot). Within each block, eight plots covering all entries were randomly selected as ungrazed controls. There was a minimum of two ungrazed control plots within each paddock with two-thirds of the paddocks having three control plots (Fig. 1). This caused the sample units to be unbalanced. These control plots had two cages (1.2 by 2.4 m) placed over the plants with the marked tillers while the paddock was being grazed. Cages were removed after grazing.

Each paddock was grazed only once during the season. The early vegetative treatment was grazed from 22 to 26 May 2000, 25 May to 3 June 2001, and 7 to 12 June 2002. The mid-culm elongation treatment was grazed from 8 to 16 June 2000, 21 to 27 June 2001, and 20 to 24 June 2002. The late-boot treatment was grazed from 30 June to 12 July 2000, 27 June to 7 July 2001, and 26 to 30 June 2002. Length of the grazing period varied depending on the amount of biomass available. Grazing was terminated when an estimated 50% of the biomass was removed relative to the controls. Average stubble height after each grazing over the 3 yr ranged from 8.5 cm for the early vegetative to 15.0 cm for the late boot. Before grazing at each morphological stage, a subgroup of 30 tillers was evaluated within each paddock to determine the average morphological stage. In late October, after a killing frost, the entire study area was mowed at a height of 15 cm to cut down the standing residue. Mowed residue was left on the plots.

Tiller recruitment per tiller is reported as the average number of new tillers from each of the marked tillers for each plant. Tillers were considered dead when there was no green material left on the tiller. Dead tillers were re-examined on subsequent monitoring dates to ensure that they were dead, not dormant. Cumulative tiller recruitment was the sum of new tillers from the marked tillers on each plant during a growing season. Cumulative tiller mortality was calculated in

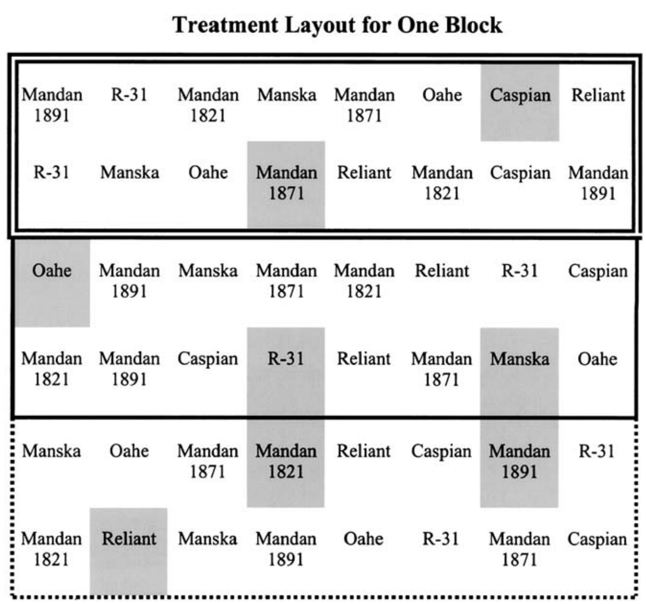

Fig. 1. Diagram illustrating the treatment layout for one block of the study. Each paddock contained 16 plots or two plots for each entry within the paddock. Shaded plots had cages placed over marked plants to serve as ungrazed controls. Each of the entries had one control plot within each block. Each of the paddocks had a different grazing treatment (double lines = early vegetative, single line = late boot, and dotted line = mid-culm elongation).

the same manner as cumulative tiller recruitment only using tillers that had died during the season.

Tiller replacement ratios were calculated to determine the net effect of tiller recruitment and mortality on the tiller numbers (Olson and Richards, 1988). Replacement ratios were calculated on the pooled data for each of the plots each growing season using the formula:

$$\frac{\text{Initial tiller number} + \text{cumulative recruitment} - \text{cumulative mortality}}{\text{Initial tiller number}} \quad [1]$$

Increasing, constant, or decreasing tiller numbers are indicated by ratios greater than, equal to, or less than 1, respectively.

Precipitation data from 1 April to 31 October during each year were recorded with an automated weather station located 0.5 km from the study site. Annual precipitation data from 1 November to 31 March as well as the long-term average (90 yr) were collected from a U.S. Weather Service site located 4 km north of the study site.

Data were analyzed using PROC MIXED (Littell et al., 1996) in SAS with year, time of grazing, and entry considered fixed effects and block as the random effect. Year was considered as a repeated measure.

Measure of tiller recruitment per tiller had a nonnormal residual distribution despite numerous attempts at transformation. Therefore, data are presented with the standard errors only. Factors were considered to be significantly different at $P < 0.05$ unless indicated otherwise.

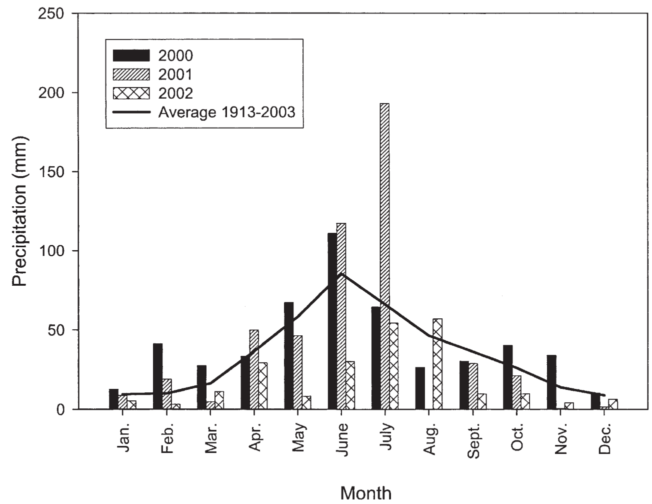

Fig. 2. Precipitation received at the Northern Great Plains Research Laboratory in 2000, 2001, and 2002 and the 1913–2003 average precipitation. Precipitation amounts for 1 November through 31 March and the long-term average were recorded 4 km north of the study site, and precipitation from 1 April through 31 October was recorded 0.5 km from the study site.

RESULTS AND DISCUSSION

The stage of morphological development in grasses is an important consideration when designing a grazing system (Mitchell et al., 1998). We wanted to determine the effect of grazing at different morphological stages of development on the persistence of eight different entries of intermediate wheatgrass. We did not evaluate plant stand or numbers of tillers per plant, both of which can affect stand productivity and persistence. We focused instead on tiller persistence because of its potential impact on future productivity. Grazing at different morphological stages affected tiller persistence, but responses varied among years. The different intermediate wheatgrass entries used in the study varied in tiller persistence.

Annual precipitation for 2000 and 2001 was approximately 120% of the long-term average (1913 to 2003), but in 2002, annual precipitation was only 55% of the long-term average. Growing season precipitation (April to September) was approximately 100, 130, and 57% of the long-term average for 2000, 2001, and 2002, respectively. From August 2001 to August 2002, precipitation was below the long-term average for each month (Fig. 2).

Effect of Time of Grazing

We used tiller replacement ratios (Olson and Richards, 1988) to determine tiller persistence. These ratios determine the net effect of tiller recruitment and mortality on tiller numbers. A year × grazing treatment interaction (Table 2) for tiller replacement ratio suggested that environmental differences and morphological stage of the plant at the time of grazing affected tiller responses to grazing.

In 2000, grazing during the early vegetative stage resulted in a significantly higher tiller replacement ratio than grazing at the late-boot stage or for the ungrazed controls (Fig. 3). A significant ($P = 0.02$) grazing treatment × entry interaction for tiller replacement ratios occurred in 2001. There were no significant differences among grazing treatments for tiller replacement ratios in 2002. A drought in 2002 lowered cumulative tiller recruitment for the grazed treatments compared with the two previous years (Table 3), resulting in lower tiller replacement ratios (Fig. 3).

Changes in tiller replacement ratios are based on the

Table 2. Significance levels, *F* values, and degrees of freedom for the factors used in repeated-measure analysis on tiller replacement ratio, cumulative recruitment, and cumulative mortality.

		Tiller replacement ratio	Cumulative recruitment	Cumulative mortality
Factor	df	*F* value	*F* value	*F* value
Year (Y)	2	6.54***	13.96***	3.92***
Time of grazing (T)	3	1.30	2.49	6.89**
Y × T	6	3.33**	4.01**	9.52***
Entry (E)	7	2.35*	2.78*	2.50*
Y × E	14	1.25	1.21	1.46
T × E	21	0.85	0.93	1.42
Y × T × E	42	1.24	1.11	1.00

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

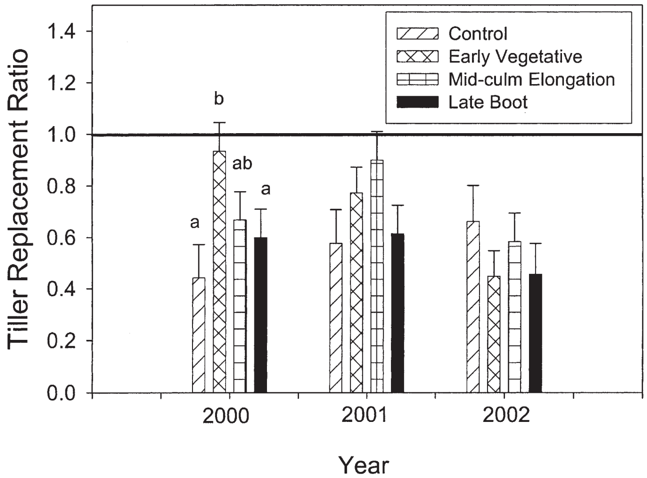

Fig. 3. Tiller replacement ratios for grazing treatment by year. Bars followed by a different letter are significantly different ($P \leq 0.05$). Line indicates a tiller replacement ratio of 1.0, the point that tiller numbers are remaining constant.

differences between cumulative tiller recruitment and cumulative tiller mortality. In 2000, all grazing treatments and entries had a net loss of tillers (Table 3). Plots grazed in the early vegetative stage had the lowest net loss, and the ungrazed control plots had the greatest net loss during this time. In 2001, grazing during the early vegetative stage resulted in a net loss in tillers while plants grazed during mid-culm elongation had the largest net gain. In 2002, only the ungrazed controls had a net gain in tiller numbers (Table 3).

Higher tiller replacement ratios for Mandan 1871 when grazed at early vegetation and mid-culm elongation caused the grazing treatment × entry interaction in 2001. When grazed at the early vegetative stage, Mandan 1871 had a significantly higher tiller replacement ratio than did Caspian (1.44 vs. 0.38 for Mandan 1871 and Caspian, respectively). Mandan 1871 also had a significantly higher tiller replacement ratio than 'R-31' when grazed during mid-culm elongation (1.75 vs. 0.42 for Mandan 1871 and R-31, respectively).

Over 3 yr, average tiller replacement ratios were highest when grazing occurred before the boot stage (Fig. 3). Although grazing during or after culm elongation reduced tiller persistence ratios in crested wheatgrass (Olson and Richards 1988), grazing intermediate wheatgrass during mid-culm elongation did not significantly reduce the tiller replacement ratios compared with the other grazing treatments (Fig. 3). Grazing intermediate wheatgrass during mid-culm elongation or earlier in the Northern Great Plains might maximize tiller regrowth (Mitchell et al., 1998), which could enhance tiller persistence.

Previous reports have indicated that intermediate wheatgrass does not persist as well as other grasses in the Northern Great Plains such as crested wheatgrass and Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski] (Campbell, 1961; Heinrichs and Clark, 1961). Averaged across entries, none of the grazing treatments or the ungrazed controls had average tiller replacement ratios equal to 1.0 (Fig. 3) in any of the 3 yr. This indicates that tiller numbers were decreasing. The lower tiller replacement ratios occurred even though some individual entries in 2001 had tiller replacement ratios that exceeded 1.0. Campbell (1961) indicated that intermediate wheatgrass should not be selected for stands intended to last longer than 3 yr, and in our study, grazing occurred during the fourth, fifth, and sixth year after seeding. Therefore, tiller numbers may have naturally been declining because of stand age, particularly for some of the older cultivars and some of the experimental strains that had not been selected for persistence. The study area was hayed for 2 yr before grazing, and this may have also affected tiller numbers. However, since haying was done on the entire study area, we assumed that all treatments would have been affected equally.

Cumulative tiller recruitment also had a year × treatment interaction (Table 2) because of differences between grazing treatments in 2000 but not the following 2 yr (Table 3). In 2000, cumulative tiller recruitment for the controls was significantly lower than any of the grazed treatments (Table 3), and grazing during mid-culm elongation and late-boot stages resulted in significantly higher cumulative tiller recruitment than grazing during early vegetative stage (Table 3). Tiller recruitment was significantly higher in the grazed treatments than in the ungrazed controls in 2000 and tended to be higher in 2001, but this difference was not significant (Table 3). These years were wetter, and larger plants may have caused shading in the controls. Shading has been reported to decrease tiller recruitment (Kays and Harper, 1974; Bahmani et al., 2000). Grazing would have reduced the shading in grazed plots and may have resulted in the greater tiller recruitment. Producers may consider a grazing strategy to reduce shading to increase tiller recruitment, especially in wetter years.

Table 3. Mean cumulative recruitment, cumulative mortality, and difference between recruitment and mortality for intermediate wheatgrass grazed at different morphological stages in 2000, 2001, and 2002.

	2000			2001			2002		
	Recruitment	Mortality	Difference	Recruitment	Mortality	Difference	Recruitment	Mortality	Difference
	tillers per plant								
Time of grazing									
Control	0.71 ± 0.56c†‡	2.89 ± 0.30b	−2.18	2.87 ± 0.92	2.36 ± 0.84b	0.51	2.42 ± 0.65	2.06 ± 0.67b	0.36
Early vegetative	1.80 ± 0.48b	2.06 ± 0.22b	−0.26	3.77 ± 0.82	4.46 ± 0.76a	−0.69	2.45 ± 0.52	4.02 ± 0.51a	−1.57
Mid-culm	3.33 ± 0.52a	4.78 ± 0.26a	−1.45	4.58 ± 0.86	4.01 ± 0.78ab	0.57	2.29 ± 0.57	3.37 ± 0.57ab	−1.08
Late boot	3.10 ± 0.52a	4.67 ± 0.25a	−1.57	3.29 ± 0.85	3.23 ± 0.79ab	0.06	1.65 ± 0.56	2.30 ± 0.58ab	−0.65

† Within columns, means followed by the same letter are not significantly different according to Tukey (0.05).
‡ Numbers after ± are standard errors of the means.

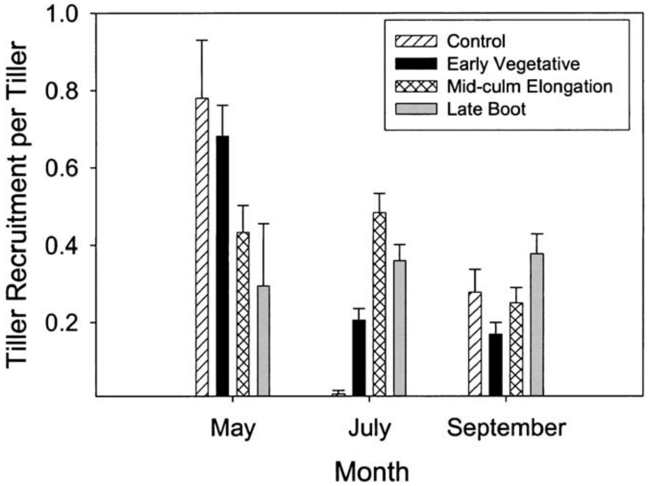

Fig. 4. Average tiller recruitment from each marked tiller for each monitoring period averaged over 3 yr for each grazing treatment and controls.

A previous greenhouse study on water stress and defoliation stress in intermediate wheatgrass suggested defoliation of intermediate wheatgrass had a greater impact on tiller recruitment than did water stress (Hendrickson and Berdahl, 2002). However, tiller recruitment tended to be lower for all treatments in the dry year of 2002 than it was in the preceding relatively wet year of 2001 (Table 3) although this difference was not testable because of a year × treatment interaction. The lower tiller recruitment in 2002 suggests that water stress did limit tiller recruitment. Tiller recruitment was also generally higher for the grazed treatments than the ungrazed control except for the mid-culm and late-boot grazing in 2002 (Table 3). These data suggest that the interaction between water stress and grazing affects tiller recruitment rather than grazing or water stress independently.

Understanding changes in the tiller recruitment patterns would be helpful for managers rotationally grazing intermediate wheatgrass. Grazing affected the timing of tiller recruitment by increasing average tiller recruitment per tiller for the grazed treatments in July compared with the ungrazed controls (Fig. 4). Grazing has been reported to change tiller recruitment patterns in little bluestem [*Schizachyrium scoparium* (Michx.) Nash] (Butler and Briske, 1988) as well as creeping bentgrass (*Agrostis stolonifera* L. var. *stolonifera*) and perennial ryegrass (*Lolium perenne* L.) (Bullock et al., 1994). Grazing during mid-culm elongation and late boot maximized tiller emergence in intermediate wheatgrass during July. Producers who need higher quality forage for livestock later in the grazing season may want to graze in the mid-culm elongation stage to maximize the number of less mature tillers.

There was a year × time of grazing interaction for cumulative tiller mortality (Table 2). In 2000, the plants grazed during the early vegetative stage and the ungrazed controls had significantly lower cumulative tiller mortality than plants grazed during mid-culm elongation or late boot stages (Table 3). Whereas in 2001 and 2002, the ungrazed controls had significantly lower cumulative tiller mortality than plants grazed during the early vegetative stage (Table 3).

Comparison of Entries

Mandan 1871 had a significantly ($P < 0.10$) higher tiller replacement ratio than R-31 (Table 4), suggesting that Mandan 1871 has greater persistence than R-31. The two entries with the greatest tiller replacement ratios in the study, Mandan 1871 and 'Manska', had significantly greater cumulative tiller recruitment than R-31 (Table 4) although R-31 had significantly ($P < 0.10$) lower cumulative tiller mortality than Manska (Table 4). Mandan 1871 also persisted well when grazed at mid-culm elongation and early vegetative stages in 2001. However, based on the tiller replacement ratios over the course of the study, none of the entries had the ability to increase their tiller numbers (Table 4). The cumulative tiller recruitment for the entries with the highest tiller replacement ratio suggests that selecting for higher tiller recruitment may be a method to improve intermediate wheatgrass persistence.

CONCLUSIONS

Grazing was less detrimental in wet years than in the dry year. Averaged over the 3 yr of the study, the greatest tiller persistence of intermediate wheatgrass occurred when grazing was done before the late-boot stage. The experimental population Mandan 1871 had the greatest tiller persistence because of its higher tiller recruitment. Differences in tiller replacement ratios between entries suggest that both cultivar selection and grazing management may increase the life of the stand. However, tiller replacement ratios below 1.0 for all cultivars and treatments indicate the difficulty in greatly extending the

Table 4. Tiller replacement ratio, cumulative recruitment, cumulative mortality, and difference between recruitment and mortality of intermediate wheatgrass entries grazed at three morphological stages from 2000 to 2002 at Mandan, ND.

Entry	Tiller replacement ratio	Recruitment	Mortality	Difference
		tillers per plant		
Caspian	0.40 ± 0.13ab†‡	1.72 ± 0.62ab	2.87 ± 0.43ab	−1.15
Manska	0.77 ± 0.12ab	3.46 ± 0.60a	4.07 ± 0.40a	−0.61
Oahe	0.75 ± 0.13ab	2.91 ± 0.62ab	3.44 ± 0.43ab	−0.53
R-31	0.38 ± 0.13b	1.51 ± 0.62b	2.54 ± 0.43b	−1.03
Reliant	0.59 ± 0.13ab	2.21 ± 0.63ab	2.77 ± 0.44ab	−0.56
Mandan 1821	0.64 ± 0.13ab	2.92 ± 0.62ab	3.39 ± 0.42ab	−0.47
Mandan 1871	0.85 ± 0.13a	3.59 ± 0.61a	3.81 ± 0.42ab	−0.22
Mandan 1891	0.72 ± 0.13ab	3.11 ± 0.62ab	3.94 ± 0.42ab	−0.83

† Within columns, means followed by the same letter are not significantly different according to Tukey (0.10).
‡ Numbers after ± are standard errors of the mean.

stand life for intermediate wheatgrass. For grazing, intermediate wheatgrass in the Northern Great Plains could fill short-term forage needs where stand longevity is not a great concern, or intermediate wheatgrass could be used as a transitional species in crop rotations. Greater tiller persistence of entries with higher cumulative tiller recruitment suggests that increasing tiller recruitment may be a method for enhancing intermediate wheatgrass persistence.

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